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Signal injector for l.f. and m.f. receivers with ferrite-rod aerials

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Research Department, Engineering Division
THE BRITISH BROADCASTING CORPORATION

RESEARCH DEPARTMENT

SIGNAL INJECTOR FOR L.F. AND M.F. RECEIVERS WITH FERRITE-ROD AERIALS

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D. Maurice
Head of Research Department

C.R.G. Reed, M.A. (Oxon), C.Eng., M.I.E.E.

(RA-49)

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SUMMARY

A transportable unit was built for the testing of l.f. and m.f. receivers. It provides more than 60 dB of screening from the effects of external fields and includes a simple signal-injection system that produces a sensibly uniform field within a volume 600 x 300 x 300 mm.

1. INTRODUCTION

Portable receivers for the l.f. and m.f. bands normally employ ferrite rod aerials. A minority of them also have the facility of using an external aerial but it is only in a very few receivers that the internal aerial can then be made inoperative. A locally generated field is therefore usually required when a signal is to be injected into a receiver for test purposes, and the results of the tests may be affected by interference from broadcasting stations, locally generated signals and electrical noise radiated by power circuits unless the receiver is screened from these interfering fields.

Although a screened room may be used for this purpose, it may be simpler to enclose the receiver within a metal box which may itself be enclosed in a second metal box. The choice of material used, ranging from wire netting to sheet metal (usually of iron, aluminium or copper) depends on many factors. Probably the most important are the degree of protection required, the range of frequencies that are of interest and the cost that is acceptable in respect of both materials and labour.

Apart from the requirement to provide a magnetic field component for injecting test signals, the design of the screening system can be complicated by the need to feed in power supplies, to take out one or more monitoring signals or to provide for direct listening to the receiver through the cage.

Systems used for injecting test signals into portable receivers usually consist of one or more loop aerials designed to produce as uniform a field as is practicable within a specified volume into which the receiver is placed. Because the dimensions of the system are very small compared with a wavelength, the receiver is excited by magnetic induction and not by a travelling electro-magnetic wave typical of broadcast reception, but this is unlikely to be of importance except for tests concerned with the design of the receiver's aerial system.

It is inevitable that the screening box, the signal injection system and the receiver's aerial will affect each other, and care must be taken to keep these interactions to a minimum.

2. SCREENING SYSTEMS

2.1. General Principles of Screening

The region inside a metal box is screened from an external alternating field – and vice-versa – by the flow of currents in the metal which produce a field that opposes the original field.

A box that consisted of a continuous sheet of perfectly conducting material, with no gaps or holes, would act as a perfect screen because there could be no electric field at its surfaces. If the source of signal were outside the box, this primary field would induce currents on the outer surface and the resulting secondary field would cancel the primary field, not only inside the box but also within the conducting metal itself. This is an extreme example of 'skin effect.'

2.2. The Limitations of a Practical Box

In a practical case the currents on the surface of the box differ from those on an ideal box, partly because the conductance of the material is finite and partly because the outer casing of the box is not continuous but contains joints and holes which disturb the current paths.

The box dimensions are small compared with a wavelength at low and medium radio frequencies and the primary field is diffracted round the box so that the incident field reaches all of the surface where it is partially reflected. The energy incident on the box that is not reflected is largely absorbed in the resistance of the box and only a small proportion of the incident field reaches the working volume inside the box.

With Hollway[1] we can consider the situation as analogous to the circuit of Fig. 1(*a*) in which a lossless transmission line with characteristic impedance Z_1 represents the propagation conditions in the air outside the box, the lossy transmission line represents the losses as the wave passes through the skin of the box and the impedance Z_C represents the coupling between the field that penetrates the box and the equipment inside it, represented by Z_L. This may, to a first approximation, be represented by the equivalent circuit of Fig. 1(*b*) in which E and the current it would drive in Z_1 alone represent the electric and magnetic components of the primary field. Z_2, Z_3 and Z_4 represent the effects of the box.

The useful screening of the box is mainly determined by two parameters, the reflexion at the boundary A, which is high if the characteristic impedance of the lossy line is very low compared with Z_1, and the loss within the wall which is largely controlled by Z_3 and Z_4.

If the box is made of highly conductive material and has an almost perfect skin the dominant factor is the reflexion due to Z_2. If the skin is complete and thick enough but the conductivity is lower there is less reflexion due to Z_2 but Z_3 is high enough to produce effective screening. If there are gaps in the skin of the box, either because there are joints or windows or because the skin is made of a mesh, Z_2 is usually still fairly low but Z_3 may be reduced considerably. Hollway gives curves relating the screening effect of a box made of fine mesh to the wire diameter and spacing and to the volume of the space enclosed. For example, the curves show that a box 1·0 x 0·5 x 0·5 m made of a copper wire mesh, the wires being 0·25 mm diameter and 2·5 mm spacing, gives an estimated attenuation at m.f. of 52 dB.

If the attenuation provided by a single screen is not sufficient it is practicable to enclose one box inside another. The equivalent circuit is then as shown in Figs. 2(*a*) and 2(*b*). The additional screening depends not only on the construction of each screen but also on the spacing between them and at u.h.f. or s.h.f. there could be resonance effects that in fact reduce the total screening compared to that of a single box. Again, Hollway[1] gives curves from which estimates may be made of the effectiveness of a double screen.

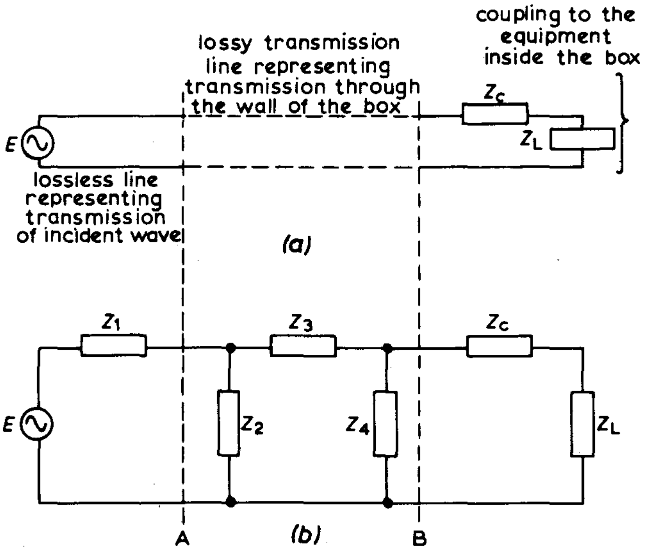
coupling to the equipment inside the box
lossy transmission line representing transmission through the wall of the box
E
Z_c
Z_L
lossless line representing transmission of incident wave
(a)
Z_1
Z_3
Z_c
E
Z_2
Z_4
Z_L
A
(b)
B

Fig. 1 - Equivalent circuit of a single screening cage

(*a*) in terms of transmission lines
(*b*) in terms of lumped impedances

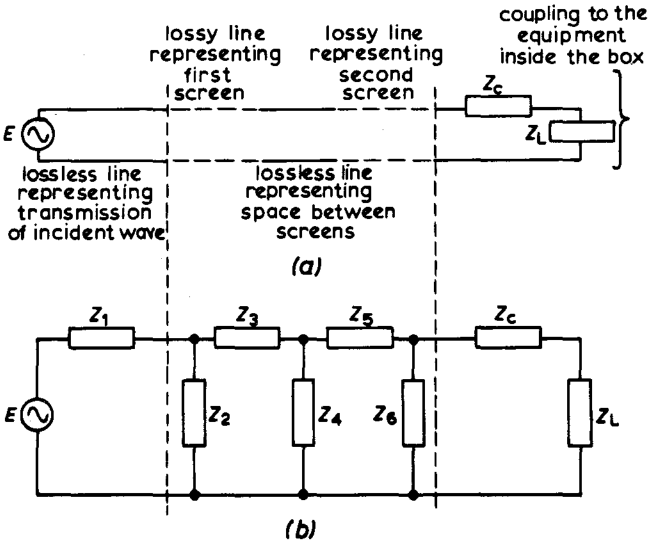
lossy line representing first screen
lossy line representing second screen
coupling to the equipment inside the box
E
Z_c
Z_L
lossless line representing transmission of incident wave
lossless line representing space between screens
(a)
Z_1
Z_3
Z_5
Z_c
E
Z_2
Z_4
Z_6
Z_L
(b)

Fig. 2 - Equivalent circuit of a double screening cage

(*a*) in terms of transmission lines
(*b*) in terms of lumped impedances

2.3. Windows in the Box

It is sometimes necessary to provide windows in the box, either for ventilation or so that the equipment inside it can be seen or heard. If the window area is small it may be possible to cover it with a wire mesh that is sufficiently transparent without excessive degradation of the screening, but when extremely good screening is required, e.g. more than 100 dB, it is usually necessary to build the window as a bundle of waveguides[3] of sufficient length and with sufficiently high cut-off frequency to provide the required attenuation. The walls of the waveguides must be bonded to the wall of the box without significant gaps but the proportion of the length of waveguide inside and outside the box is a matter only of practical convenience. The effects of a window in the wall of the box are equivalent to those of an additional impedance shunting Z_3 in Fig. 1(*b*) or shunting the equivalent elements in Fig. 2(*b*).

2.4. Electrical Connexions to Equipment Inside the Screen

It may be necessary to make electrical connexions between points inside and outside the screened box. The effectiveness of the screening will be considerably reduced unless great care is taken with these connexions. Some important factors are:—

(i) All connexions taken through the walls of the box should either be co-axial or consist of several conductors enclosed within a highly conductive sheath. In either case the outer sheath should be bonded to the wall of the box at the point of entry.

(ii) Whenever possible all conductors brought through the wall of the box but not connected to it, and all connexions to these conductors, should be completely enclosed either inside or outside the box by a screen that is bonded to the wall of the box round the total periphery of the hole through which the conductors pass.

(iii) Any conductors that cannot be screened completely — such as mains power supply leads — must be filtered at the point at which they pass through the wall of the box. Hollway[1] describes two ways of dealing with this problem.

(iv) If connexions are made through more than one hole in the wall of the box the conductors themselves and their conducting sheaths must not be allowed to form closed loops. In particular, when a double-skinned screening system is used the two layers may be joined at one, but only one, point.

3. SIGNAL INJECTION SYSTEMS

Most receivers with ferrite-rod aerials respond to the magnetic-field component of a radiated signal, with little response to an electric field. A signal injector that sets up a purely magnetic field will therefore be effective in the same way as the magnetic component of a radiated field and an equivalent electric field strength can be ascribed to it using the relationship for a uniform plane field

$$E = \eta . H$$

where E is the electric field strength in volts/metre, H is the magnetic field strength in amps/metre and η, the wave impedance,[2] is 377Ω.

A signal injector of this type normally consists of one or more conducting loops[4] carrying currents at signal frequency. The main requirements of such a system are:

(i) The loop (or loops) must not have a significant effect on the tuning or selectivity of the receiver's aerial circuit.

(ii) The signal field must be sufficiently uniform over a reasonable volume to ensure that the input signal is insensitive to small variations in receiver position.

(iii) There should be a stable relationship between the field produced and the Signal Generator output, and this relationship should not vary rapidly with frequency.

(iv) The coupling between the signal generator and the receiver should depend on the mutual-inductance component only and the alternating electric fields at the signal frequency should be too weak to be significant, even if the receiver has a moderate sensitivity to an electric field component.

The first and second requirements call for a system of one or more large loops and a compromise must be made between this and the need to keep the installation as small as possible if it is to be in the form of a portable box with screening and signal-injection facilities. The third requirement calls for both a mechanically stable design and the absence of electrical resonances at frequencies within the working range.

There is no simple formula for calculating the magnetic field at an arbitrary point due to the current in a conducting loop although particular cases can be dealt with fairly simply.[2,5] If a single circular loop is used, the volume within which the field is sensibly constant is fairly small — for a variation of ± 1 dB about a nominal value it is, approximately, a cylinder whose diameter and length are each 0·4 of the loop diameter. Thus, for a working volume 0·3 m long the loop would need to be 0·75 m diameter. If the loop were enclosed in a screening cage, the currents induced in the screen would modify the magnetic field in a way that would be difficult to predict.

More complex systems have been proposed using two coils (the Helmholtz coil system) or more, suitably proportioned and carrying suitable currents. They are usually driven in parallel by means of screened cables and passive splitting and matching units. The alternative arrangement, with a series connexion of the coils, would have a high inductance so there could be difficulty in avoiding unwanted resonances; there would also be an appreciable electric field component unless the coils were carefully screened. A long solenoid, consisting effectively of a number of single-turn coils connected in series, would have the same disadvantages but, if a cut is made longitudinally through the solenoid, the separated turns can be joined in parallel by connecting two conducting strips to the open ends, one along each side of the cut.

In the practical realization of this system the separate turns of the coil were replaced by an expanded-aluminium form of mesh which, for convenience, was bent into a rectangular box instead of a cylinder. The arrangement was thus a rectangular box with a slot cut longitudinally along the centre of the top and continued down each end from the centre of the top edge to the centre of the bottom edge. The signal drive was applied across the slot in the top in the way described in Section 4. The excitation of the two ends of the box is not ideal and the performance of the system might have been improved if there had been further investigation of this problem.

4. THE PRACTICAL REALIZATION OF A SIGNAL INJECTION SYSTEM

4.1. General Lay-Out

The equipment consists of two metal boxes, one supported inside the other on a pair of 0·1 m square bolsters made of block-board. Each box has one end removable as an access door secured by wing-nuts. The inner box (Fig. 3) is split along the top and the two ends, as explained in Section 3. At three points the slot is bridged by 1Ω resistors and the signal is injected at these points by means of a distribution transformer. The choice of the number of resistors and their values is a compromise involving the uniformity of excitation of the slot, the effects of the excitation system on the screening efficiency of the box and the ratio of the applied voltage to the resulting magnetic field strength. The whole of the inner box and one side of the outer box (Fig. 4) are of expanded aluminium and the remainder of the outer box is of 20 s.w.g. aluminium sheet.

A 75Ω socket, mounted on the end of the outer box, is used to connect a signal generator to the distribution transformer driving the inner box. A battery-driven lighting system is included in the inner box, the switch being operated by a nylon cord passing through the walls of the two boxes. This avoids the need for the filtering of power-supply leads that would have been required if an external power source had been used.

4.2. The Signal-Injection System

The signal distribution transformer has a Grade A4 Ferroxcube toroidal core, with a ten-turn primary winding and three single-turn secondaries. For convenience standard 300Ω ribbon feeder was used to connect each secondary to one of the 1Ω resistors. The connexions were each approximately 0·6 m long and care was taken to ensure that the three connexions to the slot were in the same sense. The primary of the transformer was connected to the input socket by 75Ω coaxial feeder. The impedance at the input socket, measured at 1 MHz, was equivalent to a resistance of 218Ω in parallel with an inductive reactance of 100Ω. It was decided that a network to match this to 75Ω over the l.f. and m.f. bands would be too complicated to be justified and as a compromise a 120Ω resistor was connected across the transformer primary.

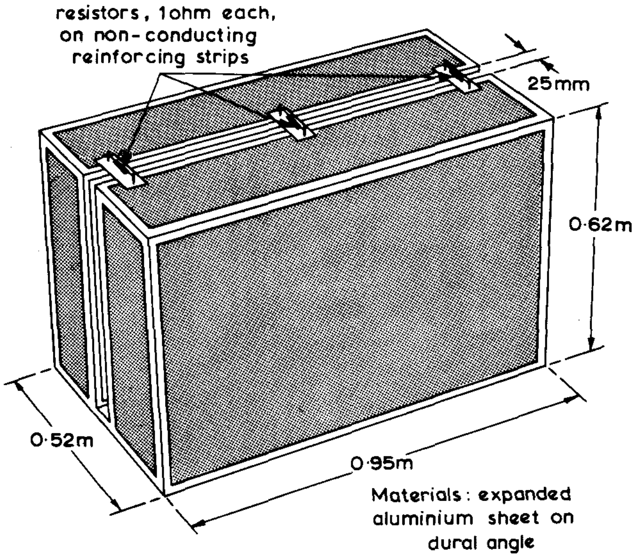
resistors, 1ohm each, on non-conducting reinforcing strips
25mm
0·62m
0·52m
0·95m
Materials: expanded aluminium sheet on dural angle

Fig. 3 - The construction of the inner box

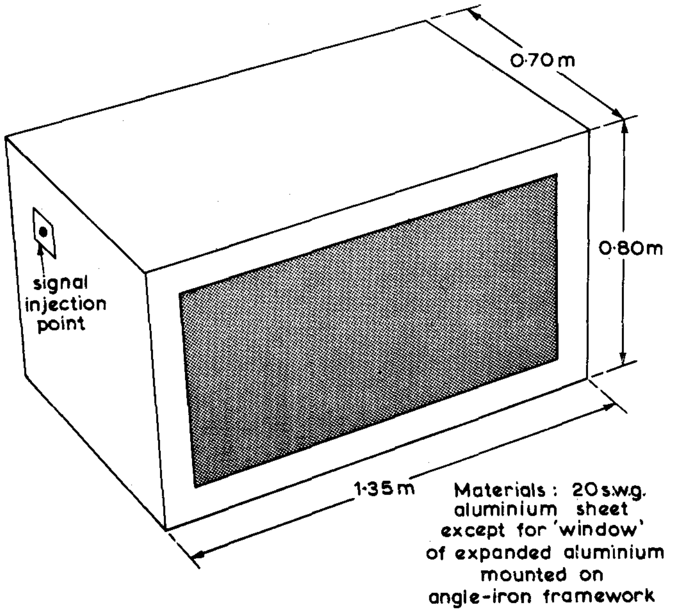
0·70 m
0·80m
signal injection point
1·35 m
Materials: 20 s.w.g. aluminium sheet except for 'window' of expanded aluminium mounted on angle-iron framework

Fig. 4 - The construction of the outer box

If another model of this signal injection system were made it would be advisable to extend the development in two ways:

(i) Modifications to the signal-injection slot at the two ends of the box could improve the uniformity of the field inside the box.

(ii) Special feeder lines could be designed for the connexion of the 1Ω resistors to the transformer. By using copper tapes separated by a thin layer of insulating material the Z_0 of the line could be made low, reducing the inductance that is effectively in series with each 1Ω load.

4.3. Field-Strength Measuring Probes

A probe was constructed to assess the uniformity of the magnetic field inside the box and as a transfer standard for calibrating the signal injection system. It consists of a 200 turn coil on a 6 mm diameter former, connected by about 1·2 m of coaxial feeder to coarse and fine variable tuning capacitors and a switch that may be used to connect fixed capacitors across them. A similar length of coaxial feeder, with a BNC plug, connects the tuning unit to an oscilloscope. The probe is inserted into the field that is to be measured, the capacitors are adjusted for resonance and the voltage read off from the oscilloscope. The probe was calibrated by means of a signal from a standard 0·3 m square single-turn loop[5] carrying a current that was measured with a thermocouple.

An l.f. field-strength measuring set, with a compact ferrite-rod aerial and meter indication of the field strength, was used to calibrate the unit over the l.f. broadcast band.

4.4. The Performance of the Unit

The inner box alone, with the distribution transformer connected, was found to have a screening effect of approximately 12 dB. This reduces the effects on the receiver of currents induced in the inner surface of the outer box by the signal-injection system. The screening of the two boxes together was difficult to measure but, with the end-doors of both units closed and a well-screened signal generator connected, it is in excess of 60 dB throughout the l.f. and m.f. broadcast bands.

The field inside the box is uniform to better than ± 1 dB within a volume of approximately 0·6 x 0·3 x 0·3 m symmetrically situated with respect to the floor of the inner box and whose centre is approximately 60 mm below the centre of the box.

The field strength within the volume is expressed as the electric field in mV/m of a uniform plane wave whose magnetic field is equal to that actually generated. The variation of field strength with frequency, for an applied e.m.f. of 1 mV from a 75Ω source is plotted in Fig. 5.

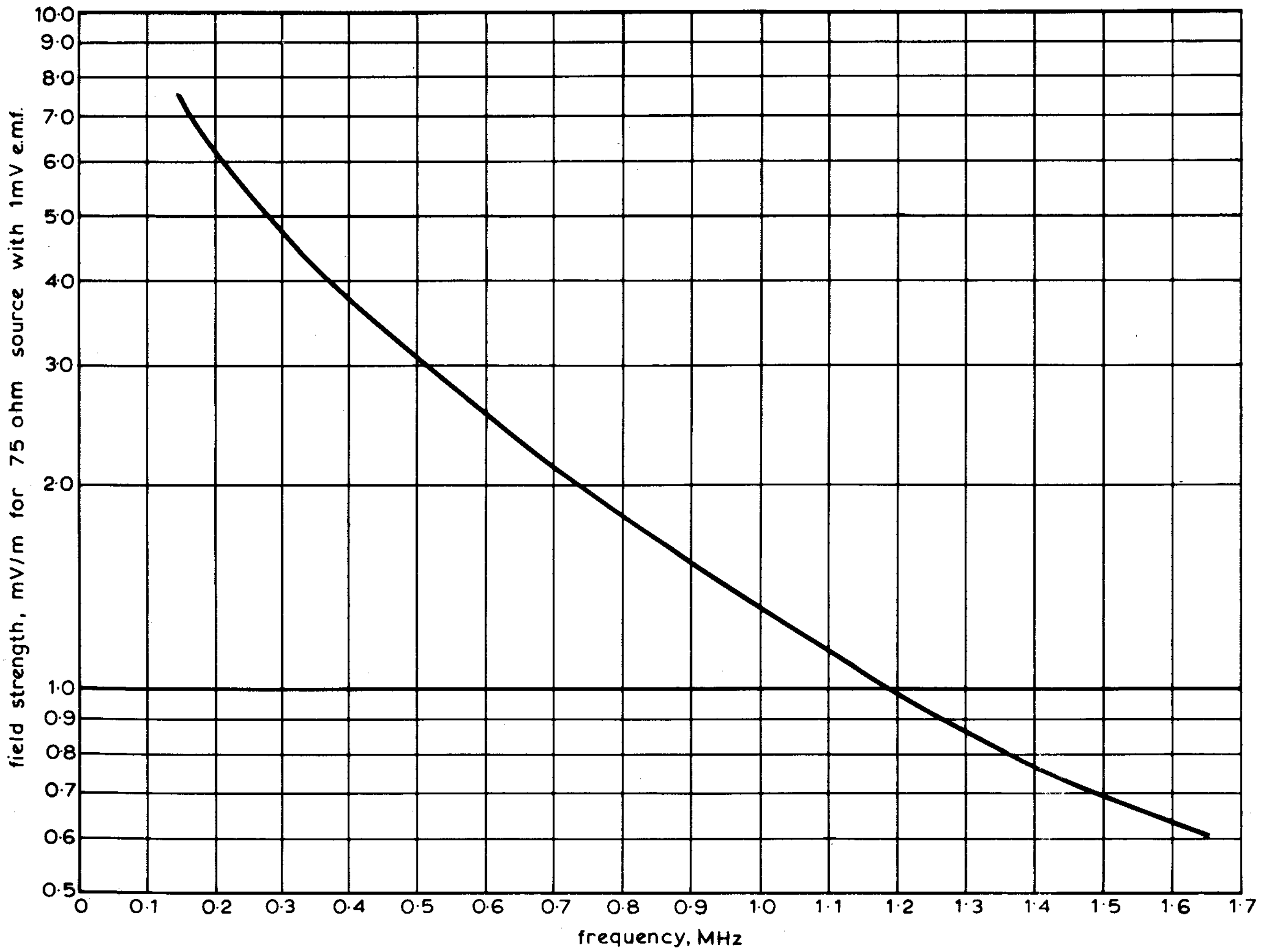

Fig. 5 - Calibration factor of the signal injector

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